Daily Rainfall Estimate by Emissivity Temporal Variation from 10 Satellites

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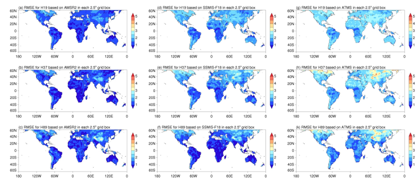
1. Background and Objectives

- Clear-sky brightness temperatures (TBs) account for ~90% of total satellite observations. Previous studies (e.g., You et al., 2014) showed that clear-sky TBs, especially the TBs at the low frequencies (e.g., 19 GHz), can memorize the previous rainfall events' effect. In other words, rainfall often lead to the surface emissivity decrease and therefore a TB depression at low frequency channels, due to the soil moisture increase.
- Such a relation (emissivity decrease due to previous rainfall events) provides an alternative way to estimate the rainfall accumulation based on the clear-sky TBs. This rainfall retrieval concept of using surface emissivity variation under the clear-sky scenario has the potential to augment the widely used ice scattering signature for rainfall estimate. Currently, the rainfall retrieval results from clear-sky TBs have not been exploited much in the retrieval community.
- This objective is to use emissivity temporal variation (Δe) from 19 GHz to 89 GHz **under clear-sky condition** to retrieve the daily rainfall accumulation. We compute the Δe from 10 passive microwave radiometers, including GMI onboard GPM, SSMIS onboard F16, F17 and F18, ATMS onboard S-NPP, AMSR2 onboard GCOM-W, and AMSUA onboard NOAA-18, NOAA-19, Metop-A and Metop-B.
- To this end, we first convert TBs from other sensors to the GMI channels (section 2); Then, we demonstrate where this method can produce reasonable result (section 3). Finally, section 4 presents the daily rainfall accumulation estimate results from Δe over GPM covered region (~65S-65N). We also discuss why a satellite constellation (instead of a single satellite) is necessary for the optimal retrieval performance in section 4.

2. Data and Methodology



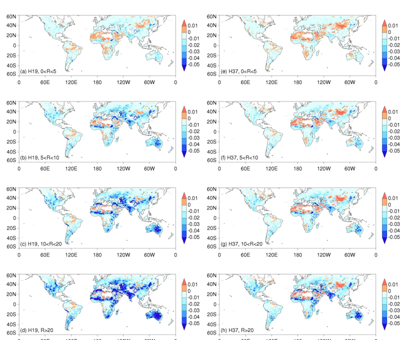
First column: the root-mean-square-error (RMSE) in each 2.5 degree grid box between GMI and AMSR2 at H19, H37, and H89. Second column: same as the first column except between GMI and SSMIS-F18. Third column: same as the first column except between GMI and ATMS. All data are from March 2014 to December 2018.

- This study uses the microwave radiometer observations from GPM, GCOM-W, F16, F17, F18, S-NPP, NOAA-18, NOAA-19, Metop-A and Metop-B. We use frequencies from ~19 GHz to ~89 GHz from each sensor.
- We first use Simultaneous Conical Overpass (SCO) technique and Principal Component Analysis (PCA) to "convert" all TBs to GMI frequencies (You et al., 2018).
- By doing so, it is as if that we have 10 sensors measuring TBs at GMI frequencies, which are 19.0 (V/H) 23.8 (V), 37.0 (V/H), and 89.0 (V/H).
- Figure on the left shows the Root-Mean-Square-Error (RMSE) due to the TB conversion from AMSR2, SSMIS-F18, and ATMS at H19, H37, and H89 channels. **Over the vast majority of the region, the RSME is less than 3 K for all channels and all sensors,** which causes emissivity uncertainty ~0.01.
- IMERG final run rainfall rate (half hour, 0.1 degree) from 60S to 60N is taken as the reference. All data (TBs and precipitation) are from 03/2014-12/2018 over land, which are averaged to 0.5 degree resolution.
- **Emissivity temporal variation (Δe) is defined as:**

$$\Delta e = e_{t_0} - e_{t_{-1}}$$

Where e_{t_0} is the daily mean clear-sky emissivity (thought rain events occur on that day), and $e_{t_{-1}}$ is the preceding daily mean clear-sky emissivity at the same location, without rainfall events.

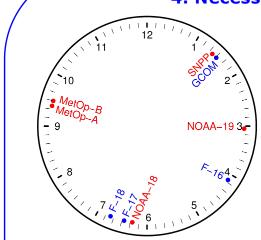
3. Where this concept works



First column: emissivity at H19, wet (rainfall occurs in previous one day) minus dry (no rainfall in previous one day) conditions. The rainfall accumulation (R) in previous one day is separated into four categories (0<R<5, 5<R<10, 10<R<20, and R>20). Second column: same as the first column except for H37.

- We compute the emissivity differences at 0.5° resolution between wet (rainfall occurs in previous one day) and dry (no rainfall in previous one day) conditions. For the wet condition, the previous one-day rainfall accumulation is further grouped into four categories, 0<R<5, 5<R<10, 10<R<20, and R>20 mm.
- Figure on the left shows the emissivity depression at H19 and H37 corresponding to the different previous rainfall amount.
- The emissivity decreases over most of the land areas after rainfall events in the previous day, and the emissivity depression increases along with the rainfall amount becoming larger.
- **The emissivity drop is particularly evident with rainfall accumulation greater than 20 mm over Sahel, Southern Africa, Middle East, Indian sub-continent, northwest China, Australia continent, and western United States.**
- This study defines the region with emissivity drop at least 0.02 with previous one-day rainfall amount greater than 20 mm as the "rainfall-sensitive-region", and daily rainfall accumulation retrieval is only performed over these areas.

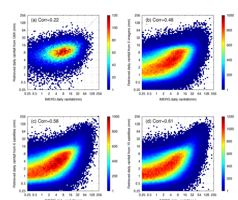
4. Necessity of Satellite Constellation and the Retrieval Result



- On the left is the Mean Equatorial crossing time (local time in the morning) for nine sun-synchronous satellites.
- Satellites with imagers onboard are in blue (i.e., AMSR2 onboard GCOM, SSMIS onboard F16, F17, and F18), and with sounders onboard are in red (i.e., ATMS onboard SNPP, AMSU-A onboard NOAA-18, NOAA-19, MetOp-A, MetOp-B).
- The GPM satellite has a precessing orbit, which means that it overpasses a certain location at varying times throughout the day.

Based on the Equatorial crossing time, and the radiometer type (imager vs. sounder), we conduct four retrieval experiments with the emissivity temporal variation (Δe) from 19 to 89 GHz derived from different sensors combinations:

- Δe derived from GMI only (**GMI-only**).
- Δe derived from five imagers, including AMSR2, three SSMISs, and GMI (**5-imager**).
- Δe derived from GMI, AMSR2, AMSU-A onboard NOAA19 and MetOp-A, and SSMIS onboard F16 and F17 (**6-satellite with very different crossing time**).
- Δe derived from all 10 satellites (**10-satellite**).



Results show that:

- The retrieval performance is poor for GMI-only, indicating by correlation being 0.22 (Fig. a). The retrieval results is much improved when using 5-imager scheme compared with GMI-only Scheme (Fig. a vs. Fig. b).
- The retrieval result is further improved when carefully selecting sensors with different Equatorial crossing times (Fig. c vs. Fig b). When all 10 satellites are used, the retrieval results are slightly improved, compared with 6-satellite scheme (Fig. d vs. Fig. c).

Two reasons are responsible for the better retrieval performance with multiple satellites: (1) The time difference between the raining day and the non-raining day is shorter with multiple satellites; (2) The emissivity diurnal cycle is better captured with multiple satellites.

Conclusions:

- **Clear-sky TB contains valuable rainfall information, which has not been exploited much in the satellite rainfall retrieval community.**
- **Our results show that the retrieved daily rainfall accumulation based on the clear-sky emissivity variation from a satellite constellation correlates well with IMERG final run product.**

References:

You, Y., C. Peters-Lidard, N. Wang, J. Turk, S. Ringerud, S. Yang, and R. Ferraro, 2018: The Instantaneous Retrieval of Precipitation Over Land by Temporal Variation at 19 GHz. *J. Geophys. Res.*, https://doi.org/10.1029/2017JD027596

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